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The Development, Design, and Testing of a Remote Sensing System to Measure Cattle Hip Height

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THE DEVELOPMENT, DESIGN, AND TESTING OF A REMOTE SENSING SYSTEM TO MEASURE CATTLE HIP HEIGHT

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ABSTRACT

The development of a cattle hip height sensor arose from the need to increase the efficiency, accuracy, and precision with which hip height measurements are taken. Eight infrared sensors were used to measure the hip height of cattle in a commercially available chute system. Stationary testing was conducted to evaluate the accuracy of the technology without the variability animals naturally impose. A repetition test was conducted as a part of the stationary tests that indicated there was no significant difference found in measured height with movement of the target forward, backward, and center. However, there was a 0.16-inch average absolute error between measured height with the left and right shifts of the target, which was a significant difference. A color test using four colors of felt fabric was conducted to suggest the effects of common cattle hair coat colors on the sensors' measurements. The color test demonstrated that the measured distances to a black target were significantly different than those to all other colors, with the exception of grey. There were no significant differences in measured target distances when using brown, white, and the bare back of the decoy. Because black colors absorb infrared light, talcum powder was added to the black fabric as a reflector, which improved the sensing ability causing an 18.97 in. decrease in absolute error at a 35-15/16 in. distance from sensor to target. This was the only significant difference in the talcum powder test. Data collection on the live animals involved the following tests: visual vs. sensor, effects of position on sensor measurements, and effects of position on visual measurements.

Talcum powder was also added to black cattle, which improved the repeatability and accuracy of the live animal tests. During live animal testing, there was no significant difference between the visual and sensor measurements. It was also found that there were significant differences in repeatability between the methods of restraining cattle to gather hip height data. Data from the visual vs. sensor comparison test was used to show the correlation between the visual and IR sensor measurements by averaging all of the measurements per animal together to represent one averaged measurement per animal this correlation provided an R^2 of 0.76. The frame score plot of the averaged data provided an R^2 of 0.75.

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INTRODUCTION

Livestock measurements are used to assist in describing a particular animal and for making management decisions. The frame score utilizes an animal's hip height as well as its age to assess the growth and performance of that particular animal. These two variables are used in equations to calculate the frame score of an animal (McKiernan, 2005).

A beef animal's height at a particular age can be used as a measure of its growth curve potential. The height of an animal can be used to estimate its growth and fattening patterns as well as its overall mature size (McKiernan, 2005). For these reasons, the frame size of an animal can be a useful tool in selecting stock. In an economic sense, proper utilization of frame score information can help a producer operate more efficiently (McKiernan, 2005).

Since 1950, the number of farms has decreased while the sizes of many farms have actually increased immensely. The United States population in 1950 was 151,132,000 people, 25,058,000 farmers, and 5,388,000 farms with an average area of 216 ac (Spielmaker, n.d.). The population of the United States in 2012 was, 3,200,000 farmers, and 2,100,000 farms with an average area of 434 ac (Busse, 2016). The increase in size of the farms called for more automation to be able to more efficiently run a farm operation. Justification of the cost of automation is also supported on these larger farms through economies of scale. When a producer collects hip height measurements on cattle, the measurements are usually taken visually with some sort of reference such as, in the case of hip heights, a measuring chart behind the animal. This method can consume a lot of the producer's time and yield inaccurate or inconsistent results, which is where an affordable remote sensing device can help solve this issue. Using remote sensing technology, this project was completed to improve the efficiency of measuring cattle hip height.

Objectives

The objectives of this study were to characterize the IR sensor ability to measure stationary objects and cattle hip heights objectively, specifically to:

- Characterize variability and accuracy of measurements
- Evaluate sensitivity of sensor system to color of target
- Evaluate sensitivity of sensor system to position of target

Review of Literature

Sharp manufactures infrared sensors that are more economical than sonar range finders, but they also offer greater performance than the other IR alternatives (Malheiros et. al., 2009). The single analog output can be connected to an analog-to-digital converter for distance measurement application. The output can also be connected to a comparator for detecting a threshold. The sensor being tested by Malheiros had a manufacturer detection range of 10 cm to 80 cm. The features of the sensor being modeled were its characteristics, the mandatory minimal distance, the sensor noise, and the influence of the sensor position while facing an obstacle. To accomplish this test an industrial robot was used to put the distance sensor in proper position in front of the object to be measured (Malheiros et. al., 2009).

Infrared (IR) sensors are often used in robots as proximity sensors because they are cost effective and offer faster response times than ultrasonic sensors. Their main function as proximity sensors is collision avoidance. One problem with infrared sensors is their nonlinear behavior. They rely on surrounding objects from which to reflect back their light. Because of IR sensors dependence on reflected light, measurements utilizing this method can be imprecise for measuring distance. Even though most IR sensors are only useful as proximity sensors, certain IR sensors are based on the measurement of the phase shift (Benet, 2002). This provides a resolution of 5 cm for distances within 10 m. One example of this type of sensor is the Sharp infrared (IR) distance sensor (model GP2Y0A21YK0F). Unlike IR sensors, ultrasonic sensors are primarily used for measuring distance. Most are relatively inexpensive and provide precision of less than 1 cm when measuring distances of 6 m or less. Ultrasonic transducers provide far less resolution than the highly directional transducers. This is the justification this team gave for researching low-cost IR sensors for use in distance measuring applications in order to reduce response times (Benet, 2002).

The amplitude response of infrared sensors depends on the reflectance properties of the target. Therefore, in order to use IR sensors for measuring distances accurately, prior knowledge of the surface must be known. The nature of how a surface scatters, reflects, and absorbs infrared light is a key component to interpreting sensor output as a distant measure. Many sensors rely on reflected light intensity to generate output as a distance measure. Some more expensive sensors generate output based on the phase shift, or the time it takes for the IR light to be sent and received (Mohammad, 2007).

For comparison purposes, ultrasonic sensors are not vision-based, and they are useful in measuring objects that are in bad lighting or transparent. However, the ultrasonic sensors do have a wide beam-width, sensitivity to mirror-like surfaces, and the inability to discern objects within 0.5 m. Because of the mirror-like nature of an ultrasonic wave reflection, only reflecting objects that are almost normal to the sensor's acoustic axis may be detected. If the object being measured has unknown characteristics, ultrasonic sensors can help to determine surface properties to assist in the disadvantages of the IR sensors. Utilizing both of these sensors for the same measuring task can allow the ultrasonic sensor to make up for the disadvantages of the infrared sensor and vice versa (Mohammad, 2007).

An experiment was performed using the ultrasonic sensor UB400-12GM-U-VI and an infrared sensor setup with one LED and two silicon phototransistors (Mohammad, 2007). To determine the surface properties and how the sensors react to them, it was necessary to calibrate both sensors. The calibration of the ultrasonic sensor revealed that this particular sensor was dependent on the distance and orientation of the obstacle relative to the sensor. The sensor output did not depend on the color of the surface or the smoothness of that surface. To calibrate the infrared sensor, they used a variety of objects with various color and surface smoothness.

These surfaces were silver finished metal blocks with smooth surfaces, white plastic board, unfinished wood, and a black notebook with rough surface. This calibration revealed that the amplitude of the IR sensor was dependent on the object's ability to reflect infrared light. Certain environmental conditions such as sunlight and artificial lights unless the light is directly pointed at the sensor can affect sensor performance. From the data collected from this calibration, it was apparent that the infrared sensor had a nonlinear characteristic (Mohammad, 2007).

The accuracy of the ultrasonic was from 90 to 97 percent as opposed to the infrared sensor, which was from 92 to 95 percent. The standard error for the ultrasonic sensor was lower than the infrared sensor, so it could be concluded that the ultrasonic sensor had lower resolution than the infrared sensor for small distances. (Mohammad, 2007). These experiments indicated that the inexpensive ultrasonic and infrared sensors can provide reliable distance measurement.

Marshall S. Kriesel has established methods and a device for measuring cattle hip height and other dimensions from the use of a single-camera system. The primary goal of this system was to obtain animal weight, animal hip height, and animal hip width. The goals sought to be achieved with this system were to provide greater accuracy and speed in acquiring these measurements. The system takes advantage of the fact that hip height and width are oriented orthogonal to each other; the camera axis is aligned to one livestock measurement thereby allowing the second measurement to be at a right angle to the camera axis. The measurement acquired orthogonal to the camera axis is acquired by a known dimension of an object in the picture. The measurement in-line with the camera axis is converted to an orthogonal view and measured against the calibrated dimension. He uses live animals in various positions to test his system (Kriesel, 2006).

Trent Smith of the Mississippi State Extension Service presented his comparison of different methods of evaluating cattle hip height and weight at the 2012 BIF National Convention. His goals were to evaluate different methods in measuring cattle hip height, assess the use of a head gate in relation to hip height data accuracy, and determine the repeatability of specific measurements with different observers. The first method he used was the visual assessment with a measuring chart behind the cow in the chute. The second method was the use of a tape measure, measuring the distance between the top of the chute to the hips and the distance between the top of the chute to the floor. The third method was the use of an altitude stick. He also conducted these measurements with the head restrained and unrestrained. He found that as cattle temperament became more violent, the less precise and accurate the hip height measurements were. For cows, correlation coefficients between observers decreased as the chute score increased ($P < 0.01$). For calves, the correlation between the observer's chute score increased as hip heights decreased ($P < 0.01$). Further, he recommended, based on this study, that cattle should be unrestrained when measuring hip heights (Smith, 2012).

MATERIALS AND METHODS

Developing a system for measuring cattle hip height began with the design process. Initially a mechanized design was considered. This design would allow for the sensor to be positioned precisely above where the measurement needed to be taken on the animal using only one sensor. A single sensor would be mounted on a linear track which would be able to change position through operation of a reversible motor as it appears in Figure 1. This track would be supported by two rails, which would functionally suspend the system over the chute. This mechanized design concept was abandoned because it thought to be impractical for use in a cattle operation setting. The cost of components in this design was $580, which was about $200 more than what the stationary design cost to build. The primary reason this design was abandoned was a result of the DC motor being too slow. If the motor is too slow, it holds up the process of measuring the animals thus it wastes the producer's time. It was decided that the design needed to be stationary with no moving parts.

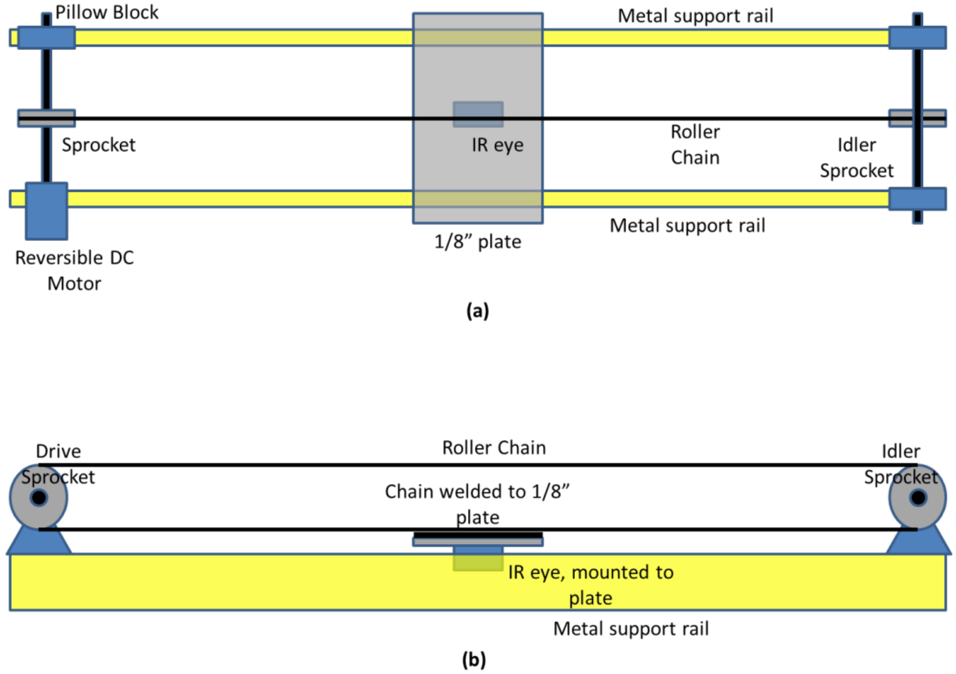


Figure 1. Concept design for mechanical hip height measurement system:
(a) top view, (b) side view.

The design that was planned next was a stationary design that would be mounted to a squeeze chute. This design consisted of a wooden mount that would be mounted lengthwise on a cattle chute as seen in Figure 2. On this mount, a PVC electrical enclosure box containing the USB interface kit or I/O Board, model 1018_2 (Phidgets Inc., Calgary, Alberta, Canada), and infrared distance sensor adapters, model 1101 (Phidgets Inc., Calgary, Alberta, Canada), were mounted on top of the wooden platform with the wiring connecting the sensors to the I/O Board routed out of the way. Each chute to be used in the test would have its own wooden mount. The sensor plate consisted of a rectangular plate of 0.125 in. thick sheet metal with two carriage bolts welded to it to secure it to the wooden mount. On the steel plate was a row of eight infrared sensors set at 4.5 in. apart with which the hip height measurements were taken. The Phidgets IR sensors, model 3522_0 (Phidgets Inc., Calgary, Alberta, Canada), were mounted directly to the metal plate using machine screws.

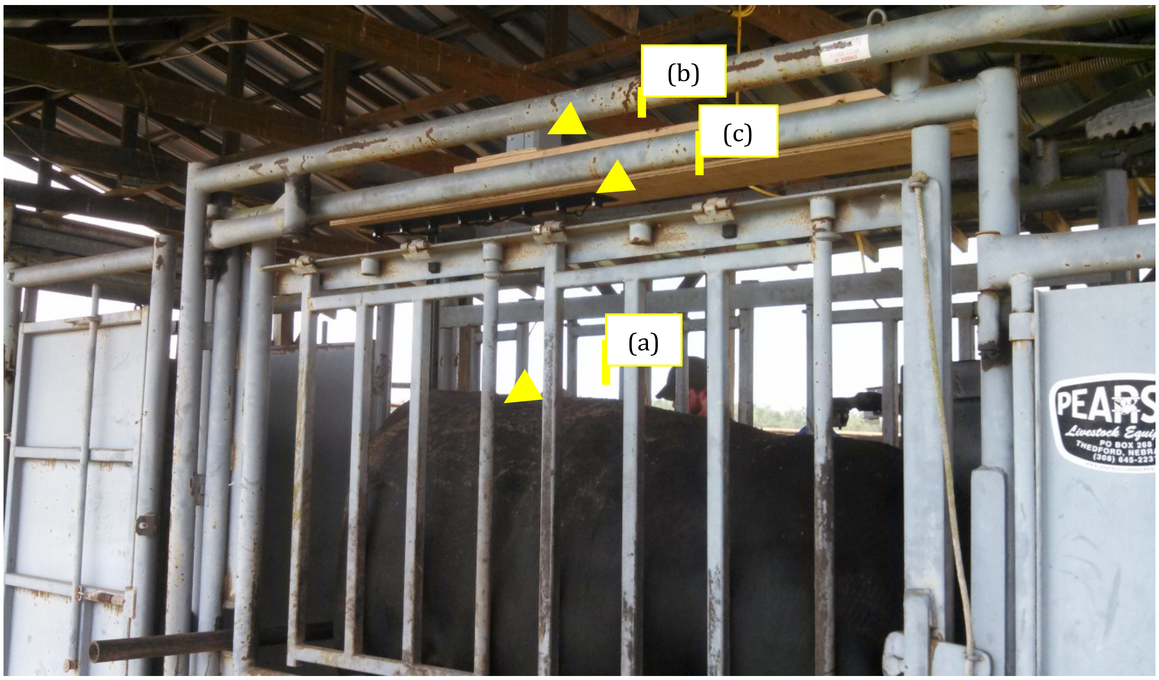


Figure 2. General physical arrangement of components of IR hip height measurement system: (a) target area (space directly between the iliums); (b) junction box containing I/O board, adapters, and wiring; and (c) sensor array along metal plate.

This version of the hip height sensor was used for all of the tests in 2014 and parts of 2015. The main issue we noticed with this system is that it was not adaptable to different kinds of cattle chutes. After analyzing this problem, the wooden design was discarded, and the final design was planned.

The design that was chosen for the remainder of the project was very simple compared to the other two designs, as seen in Figure 3. This design consisted of perforated channel iron, which had holes along its length for mounting clamps and the steel plate on which the sensors were mounted. The key feature of this design is that it straddled the chute allowing it to accommodate a larger variety of chute systems. It was also less bulky thus allowing it to be more portable. In the previous system, there was a wooden mount on each chute for the sensor plate to attach. In this system, the sensor plate mounted directly to the chute allowing for a more versatile system.

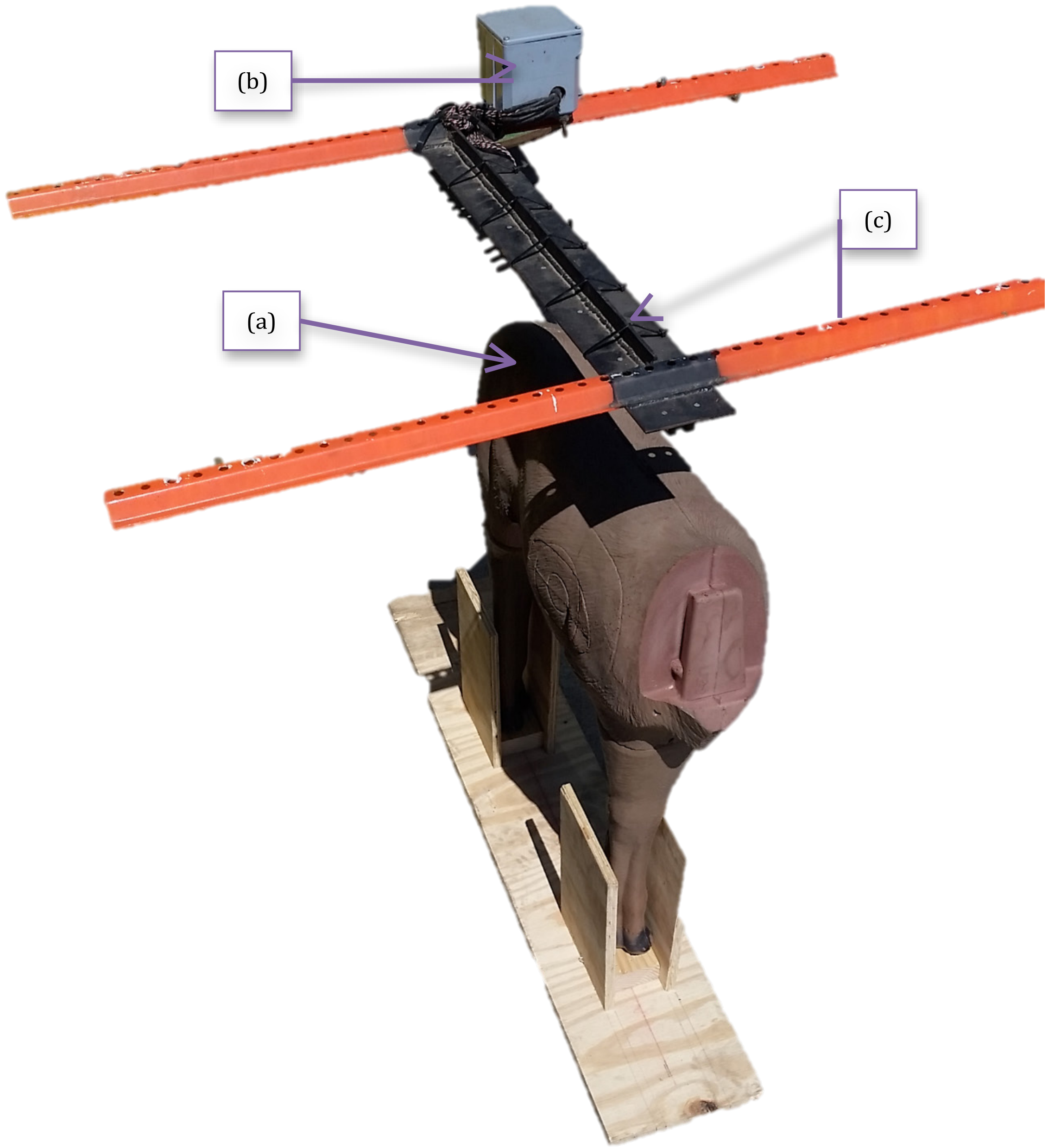


Figure 3. The updated metal sensor setup: (a) target area; (b) box containing I/O board, adapters, and wiring; and (c) updated sensor mount.

A Panasonic Toughbook® ran data acquisition software written using Visual Studio® (Microsoft Corporation, Redmond, Washington). The computer code underwent many changes in user interface as the project progressed. The biggest improvement to the program was having the sensor selection changed from clicking a radio button to actually typing the corresponding sensor number on the keyboard for a "one touch" sensor selection process. This improved the data collection process tremendously. There was too much room for error when the system required clicking a radio button for the sensor selection. For example, whenever an animal would stand in the proper position to be measured, the operator of the program would have to move the cursor over the proper radio button and click it to choose the proper sensor allowing time for the animal to change position before the operator can measure it with the sensor. Some other improvements that were made were related to documentation by the inclusion of dropdown boxes to include information such as breed, age, laser hip height, and visual hip height. The sensor update rate was 2 Hz. The user interface of the data acquisition program as it appeared on the computer can be seen in Figure 4.

The calibration process was the next step. Calibration was completed by placing objects at a known distance under the sensors, taking a reading, and incrementally changing the distance to create a calibration curve. Two separate calibrations were created as seen in Figure 5 and Figure 6. A separate calibration was created for each sensor because it was found that sensor response varied somewhat. Calibration was done to correct for these factors and have the systems operating the same. A calibration was conducted for a sensor system used at the Edisto Research and Education Center, and another was for a system used at the Simpson Research and Education Center. Distance to target was found to be best represented as a power function of sensor response. The calibration curves created independently for each sensor on each system was implemented in the computer program to calculate distance to target.

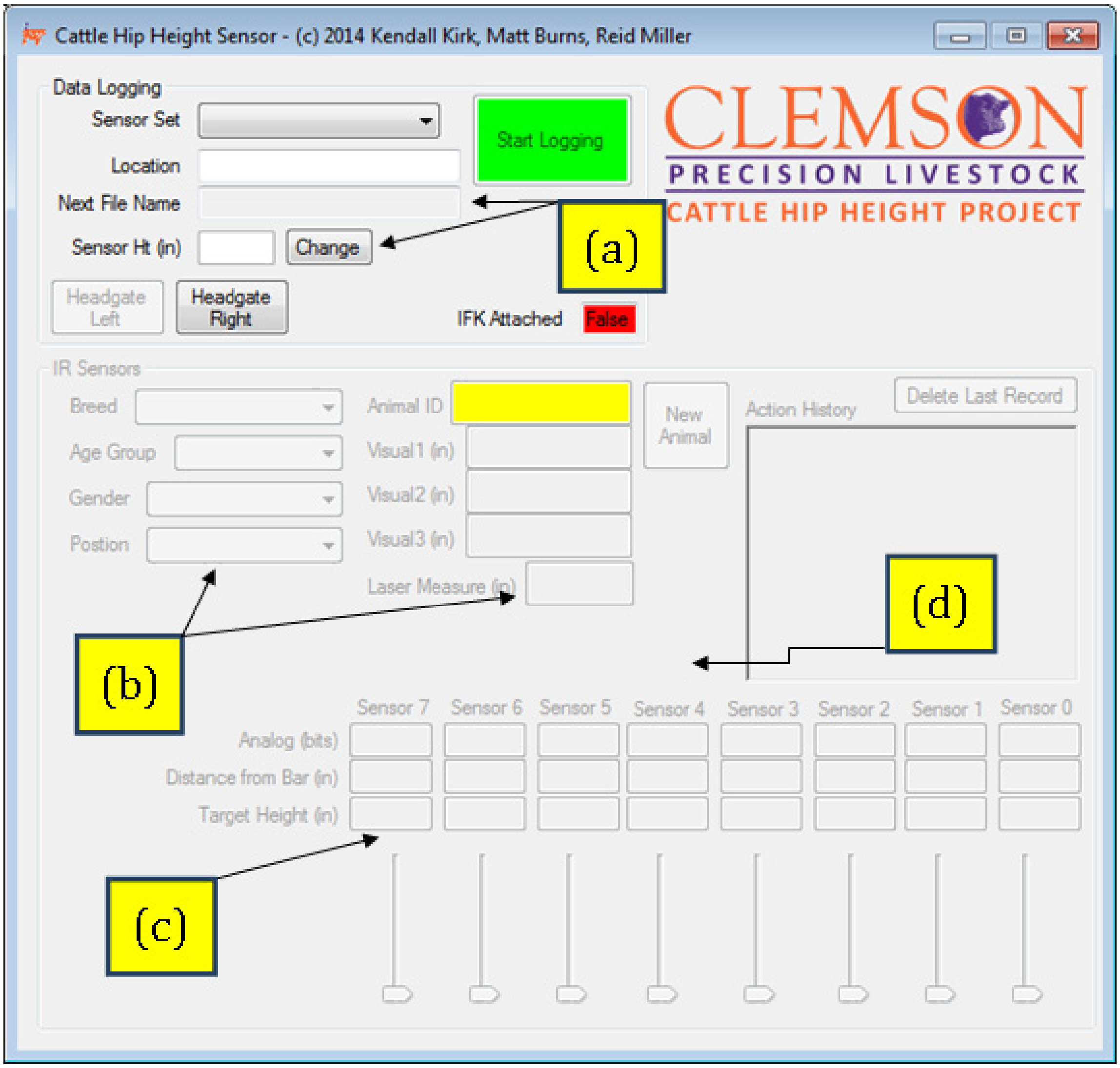
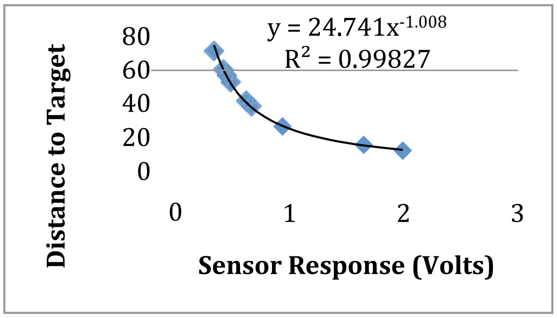


Figure 4. Screenshot of the final program layout as it appeared on screen, where (a) indicates where data logging information was entered, which sets a location and name for the file, (b) indicates where the animal information and measuring details were entered, (c) indicates infrared sensor readings as they occur every half second, and (d) indicates where the sensor selection box appeared once the "Start Logging" button was clicked.



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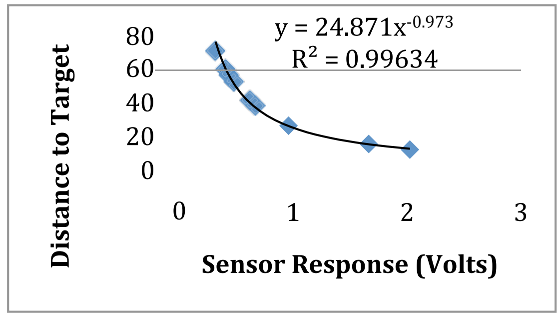

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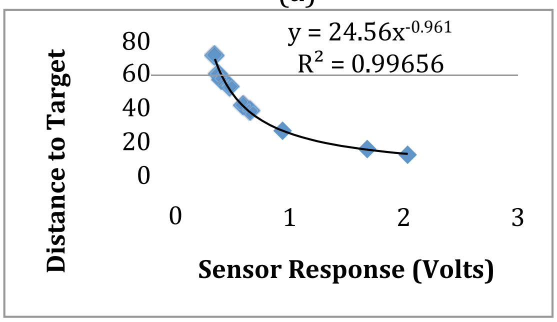

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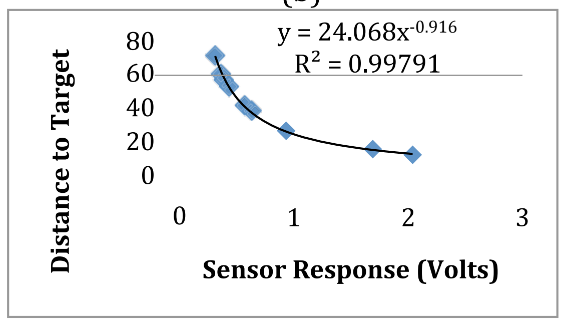

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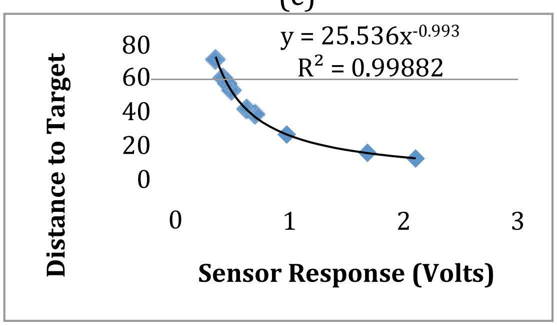

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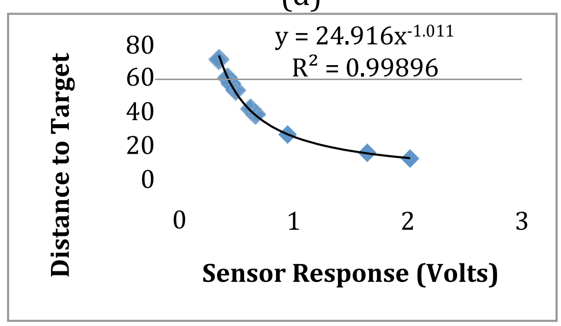

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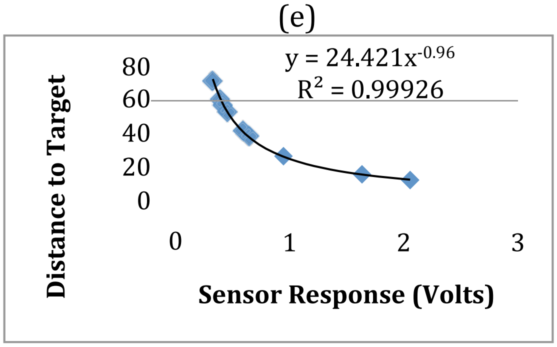

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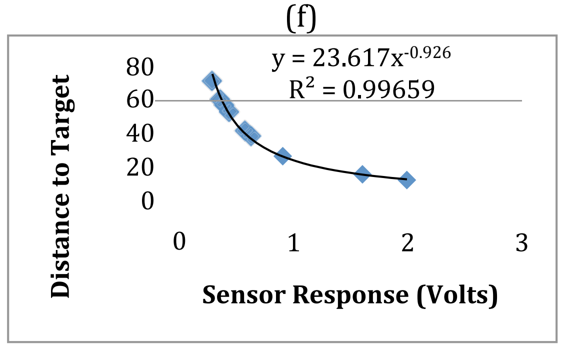

(h)

Figure 5. Infrared sensor calibration for sensor assembly used at Simpson REC, where (a) represents Sensor 0, (b) represents Sensor 1, (c) represents Sensor 2, (d) represents Sensor 3, (e) represents Sensor 4, (f) represents Sensor 5, (g) represents Sensor 6, and (h) represents Sensor 7.

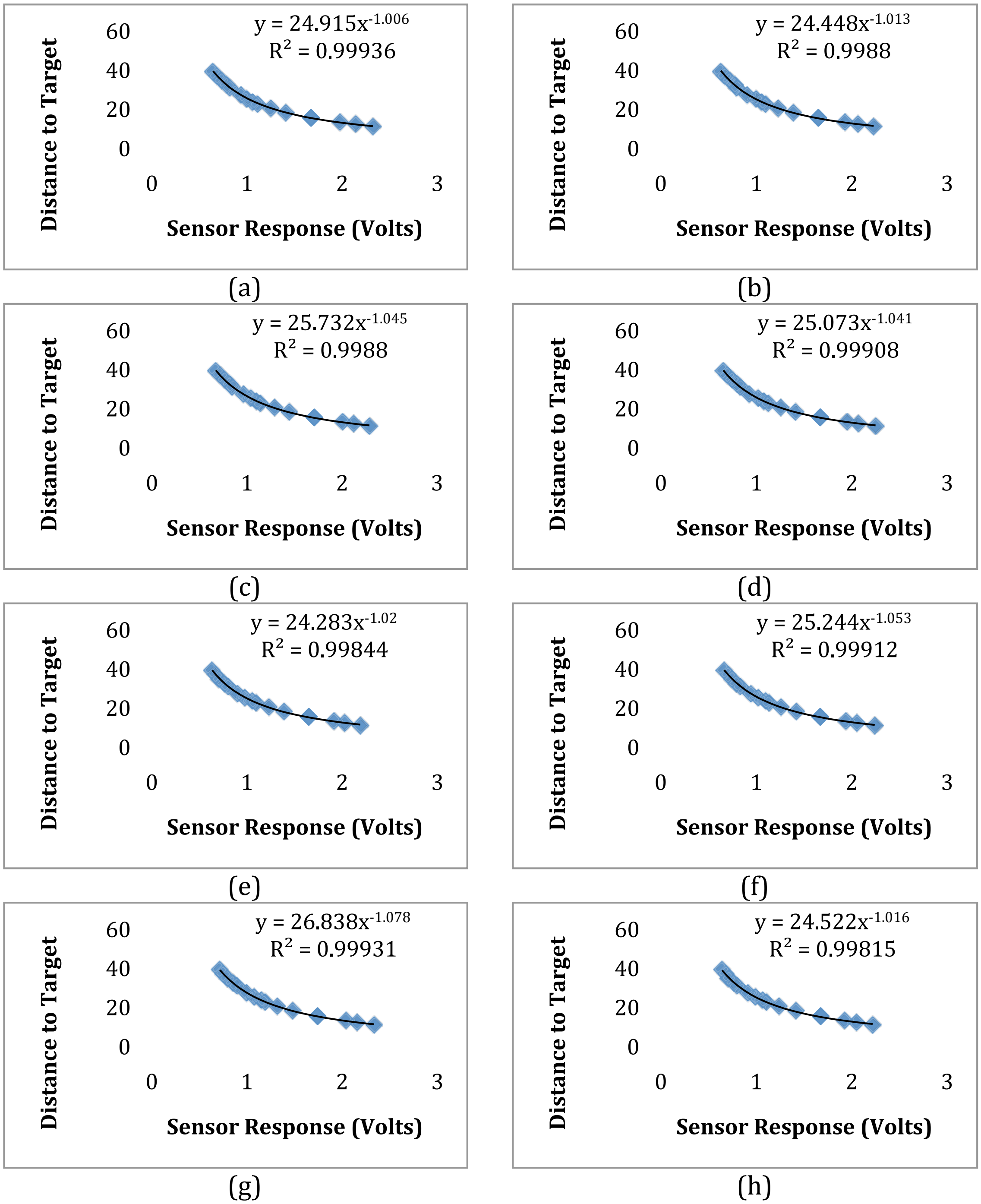

Figure 6. Infrared sensor calibration for sensor assembly used at Simpson REC, where (a) represents Sensor 0, (b) represents Sensor 1, (c) represents Sensor 2, (d) represents Sensor 3, (e) represents Sensor 4, (f) represents Sensor 5, (g) represents Sensor 6, and (h) represents Sensor 7.

Several stationary tests were performed to evaluate the precision and accuracy of the sensors without the effect of animal movement. This also helped to establish how these sensors should be used to measure animals. Three types of tests were used to evaluate the sensors using inanimate objects: centering test, color test, and powder test. All of these tests arose from issues observed in some of the preliminary tests conducted on live animals. Variability was unusually high in some cases, so these tests were used to attempt to pinpoint the problems.

The centering tests were used to, basically, define the sensors' range of measurement and to suggest effects of animals being positioned off-center beneath the sensors. The color tests were an attempt to observe sensor variability based on colors commonly present on cattle hair colors. The powder tests arose from the color test and were meant to see if the talcum powder had any correctional effect on measurements made against the black fabric.

The centering tests were conducted mostly at the Balk Place at the Edisto Research and Education Center. These tests involved shifting a target laterally, longitudinally, and vertically. The first set of centering tests involved shifting a deer decoy left and right in measured increments. A random number generator was used to randomize the treatment order. The items used in this test were: Panasonic Toughbook, the updated sensor set, structural supports to properly level the sensor set above the target, two 2x6 boards, plumb bob, tape measure, combination square, plywood platform (to mount and stabilize the deer decoy), and a deer decoy.

To analyze all of the data that was collected, a statistic known as average absolute error was used to quantify measurement error. For example, if an object was measured five times, all five of those measurements would be averaged. This average was then subtracted from each individual measurement to find the individual measurement error. After the error was calculated, the absolute value of the error was calculated. The absolute values of errors were averaged to calculate the average absolute error. Comparison of average absolute errors was used to determine whether or not there were significant differences present because this was a true and tangible measure of error.

Centering Test: 12 in. Distance

For the first centering test, the sensor set was mounted 12 in. above a target on the deer decoy being measured as seen in Figure 7. To do this, all four corners of the sensor mount were measured to be sure that it was completely level. A small mark was etched on the decoy to have a point of reference for the center of the decoy's hip. Measurements were taken at .25 in. intervals with the maximum value being two in. on the left and right. Five consecutive sensor readings were taken every 1/4 in. followed by the next interval by shifting the deer decoy left or right. Each interval was measured by placing a tape measure at the base of the deer decoy platform in order to keep track of measurements and to keep the deer in line with the sensor set.

Figure 7. General layout of centering test at 12 in. from the target.

Centering Tests: 18 in. Distance, 26 in. Distance, and 14 in. square

The centering test at the Balk Place of Edisto REC was carried out in the alley behind the squeeze chute. This provided the conditions to properly space the sensor set and the deer decoy to more closely resemble a cattle-working setup. The deer was roughly 18 in. from the sensor set. A plumb bob was used to align the deer decoy directly under the sensor set. After the decoy was aligned, a combination square was used to mark a set of 1/4 in. intervals on both boards to the left and right of the decoy. The decoy and the board below it were marked where they crossed to prevent any forward or backward movement. Before executing the test, all of the test intervals were randomized in Microsoft Excel®. Sensor readings were taken according to this random order, with only one repetition. The same test was performed again on the deer decoy at a target distance 26 in. from the sensors. This test was also performed on a 14 in. wide wooden square to demonstrate the allowable chute width.

Centering Test Manual Measurements

To have a physical standard for comparison to the sensor data, manual measurements were taken on the decoy using a level and a set of dial calipers. The level was placed across the decoy's back and used to take depth measurements of the decoy's hip with the calipers. Starting from the center and measuring from the bottom of the level to a point on the decoy, a rear profile of the decoy's hip was manually developed with which to compare the sensor readings. Five repetitions were done for each interval.

Color Test

The color test was conducted to test the effect of various colors on the sensor readings. In preliminary testing, it was observed that the sensors demonstrated erratic readings measuring some cattle with black hair color. Four different colors were tested with four 8 in. x 12 in. sheets of felt per color for a total of sixteen sheets. The colors were brown, black, grey, and white, which were selected because they are all commonly occurring in cattle coat color.

The color test was conducted using the same setup as the centering test at the Balk Place. A plumb bob was used to align the deer with the sensor set. Weights were attached to the fabric to insure the fabric would remain flush against the decoy's back once placed there. A random number generator was used to randomize the order in which the colors were tested for each replication. One reading was taken for each color for five replications. The general layout for the repetition test can be seen in Figure 8(a).

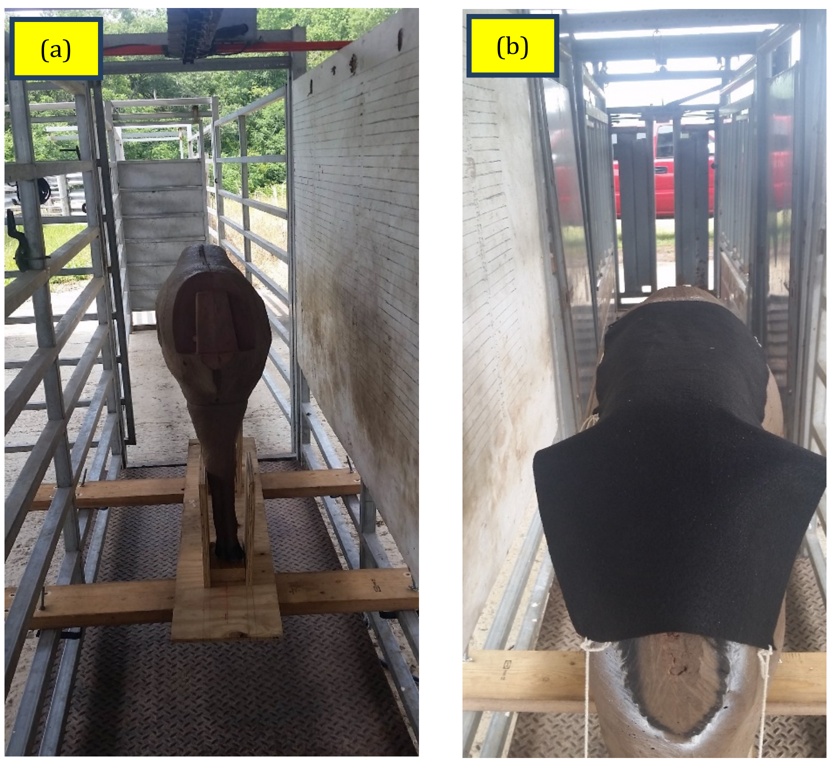

Figure 8. General setup for (a) repeatability test and centering test, and (b) color test at the Balk Place inside of the alley.

Repetition Test

The repetition test was conducted at the Balk Place of Edisto REC between the set of panels behind the squeeze chute. Although this test also involved moving the target such as was conducted in the centering test, the purpose of this test was to measure repeatability of the sensors to different target areas, as shifting the deer decoy resulted in different, but repeatable target distances. For this test, a plumb bob was used to align the deer decoy. One in. intervals were marked along the base of each side of the deer. The marks on the base of the deer and marks on the boards that was being used as a platform created an XY plane. This plane was used to position the decoy 1.0 in. to the back, on center, 1.0 in. to the front, 1.0 in. to the left, and 1.0 in. to the right, for five replicates. To avoid confusion with the centering tests, these positions are denoted in the results as positions one through five, respectively. A random number generator was used to keep the position order random for each replication.

Powder Test

The powder test was conducted using black felt, talcum powder, a 2x4 board, two 2x6 boards, and a plumb bob. To begin, the two 2x6 boards were laid over top of and perpendicular to the rails lining the alley behind the squeeze chute. The 2x4 was laid over the top of and perpendicular to the 2x6 boards. Once the boards were laid out, one black sheet of felt was coated with talcum powder and the other was left as it was, uncoated. This test was performed at three different distances from the target: 18-15/16 in., 27-3/8 in., and 35-15/16 in. Using a random number generator, the order of the readings was randomized, providing five replications at each target distance.

LIVE CATTLE TESTS

The live cattle tests were performed at the Edisto Research and Education Center. The testing sites were the Balk Place and the Soup Bowl. The materials used during these tests consisted of: Pearson squeeze chutes; panel-assembled alleyways; a hip height board consisting of plywood and permanent marker inch lines that spanned the backdrop of the squeeze chute; a Panasonic Toughbook® and Ram Mount for mounting the computer to the chute; the metal sensor mount on which the I/O Board, distance adapters, and infrared sensors were mounted.

The purpose of the live cattle test was to observe how the sensors performed against the visual method with one person. Other variables being tested using the sensors on live animals were coat color and position. The first test was simply a positioning test with and without talcum powder. The second test was a positioning test using only baby powder to negate the effects of black hair color. This test was used to compare sensor readings and visual readings for each of four positions/restraints: freestanding, free/squeezed, head caught, head caught/ squeezed. In the freestanding position, the animal was free to move within the confines of the chute with no restraint. In the free/squeezed position, the animal was allowed forward and backward movement but was very limited in its lateral movement due to the application of the squeeze. In the head caught position, the animal's head was caught in the head gate with no squeeze applied. In the head caught/squeezed position, the animal's head was caught and the squeeze was applied, which allowed for the maximum restriction of movement the squeeze chute could provide.

The first repeatability tests were for comparison of the infrared sensor measurements to visual measurements on eight individual animals, all black in color, in the alley behind the squeeze chute. The sensor set was placed on top of the alley parallel to the cattle as they walked through. It was from this test that the final method of cattle testing was performed to test the effect of position and color on infrared sensor response. Absolute average error, as defined previously, was again used to determine if significant differences existed among the data. For the live cattle tests, there were four variables that were tested: the effect of cattle hair color on the sensor accuracy and repeatability, visual measurements vs. sensor measurements, the effect of animal position/restraint on visual measurements, and the effect of position/ restraint on sensor measurements.

Hair Color/Talcum Powder Test

Tests were conducted to evaluate the effect of hair color on the sensor measurements. The first test conducted was strictly a positioning test with only black color. This group was tested at the Soup Bowl and consisted of five predominately black cows, 1,200 to 1,250 days of age, and one partially black steer, about 518 days of age for a total of six animals. These animals were cycled through the chute a total of three times and no more to reduce stress. Each caught/squeezed position. At the end of this test, eighteen measurements without talcum powder were gathered for each position/restraint. The second test group was the group on which talcum powder was applied to the target area. The second test group was at the Balk Place and consisted of six predominantly black heifers, 480 to 540 days of age. The measurements taken on these were visual and sensor- based using the same positions mentioned in the first test group. Each heifer was measured in all four positions three times using both the visual method and the infrared sensors.

Comparison of Visual to Sensor Test

To evaluate the visual measurements versus the sensor measurements, a test was designed to compare the variability between the infrared sensors and the conventional method, which entailed collection of visual hip heights, using only one observer, against a measuring chart in the backdrop of the chute. A group of heifers was used on three different days. Measurement of the heifers was spread out over three days to reduce animal stress, which may have also improved animal disposition and therefore reduced error in the results. Six predominantly black heifers were used on the first day. Four animals with four replications were used for the next two days because using six animals with three replications seemed to put too much stress on the heifers. Each heifer was measured in all four positions/restraints for each replication using both the visual method and the IR sensor method to quantify the repeatability of both of these methods across different positions. At the end of the test there were 47 measurements for freestanding, 48 measurements for free/squeezed, 47 measurements for head caught, and 48 measurements for head caught/squeeze.

ERROR ANALYSIS

The physical measurements using calipers provided a standard which was used to compare to the sensor readings taken on the deer decoy. When the deer decoy sensor data and physical measurements data are applied to the same chart, seen in Figure 9, we can compare how close the sensors came to capturing the actual cross-sectional shape of the deer decoy.

The deer decoy was used instead of a live animal to reduce the variability naturally imposed by the live animal, but the drawback was that the profile of the deer decoy does not absolutely represent the profile of a cow. These results suggest that the sensor does not accurately measure distance to target when the target plane is not perpendicular to sensor because the deer decoy does not have a flat zone, as is present on a cow, as indicated on the physical measurements. The sensor response in this test is rarely in response to a target plane perpendicular to the sensors. The effect is more pronounced at a greater distance from the target, presumably because the reflected infrared light may therefore be farther from the sensor.

From differences in sensor responses relative to movement left and right, it was observed that direction of the planar angle of the target affected sensor response. When the decoy was shifted to the left, the sensor was centered over the right side of the decoy and vice versa. These observations led to the 14 in. square test in order to get a truly flat surface to measure. This flat, plywood surface allowed for a better gauge of how exactly these sensors viewed a target, and it allowed for the observation of any major error that was sensor based. From this data, a scatter plot was formed showing how error increased with chute width, assuming an animals flat zone and total width are taken into account, as seen in Figure 10.

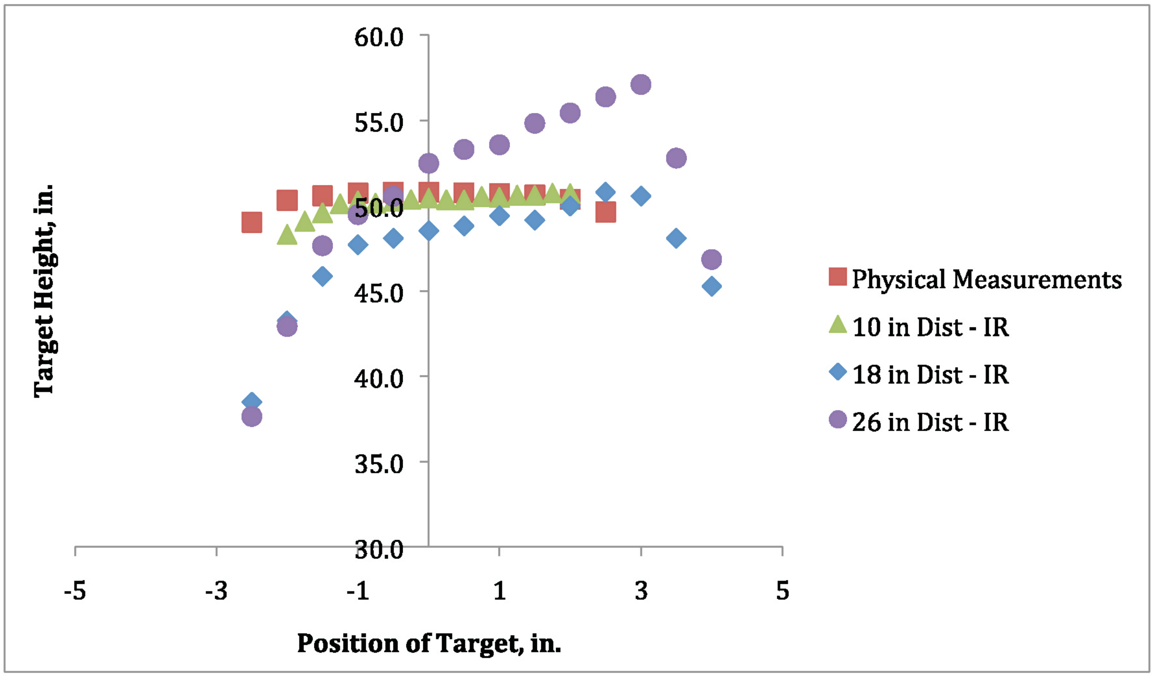

Figure 9. Chart showing the comparison of the measurements taken at 10 in., 18 in., and 26 in. from the target compared to the physical measurements on the deer decoy where 0 represents the center, the negative values represent the left side of the decoy, and the positive values represent the right side of the decoy.

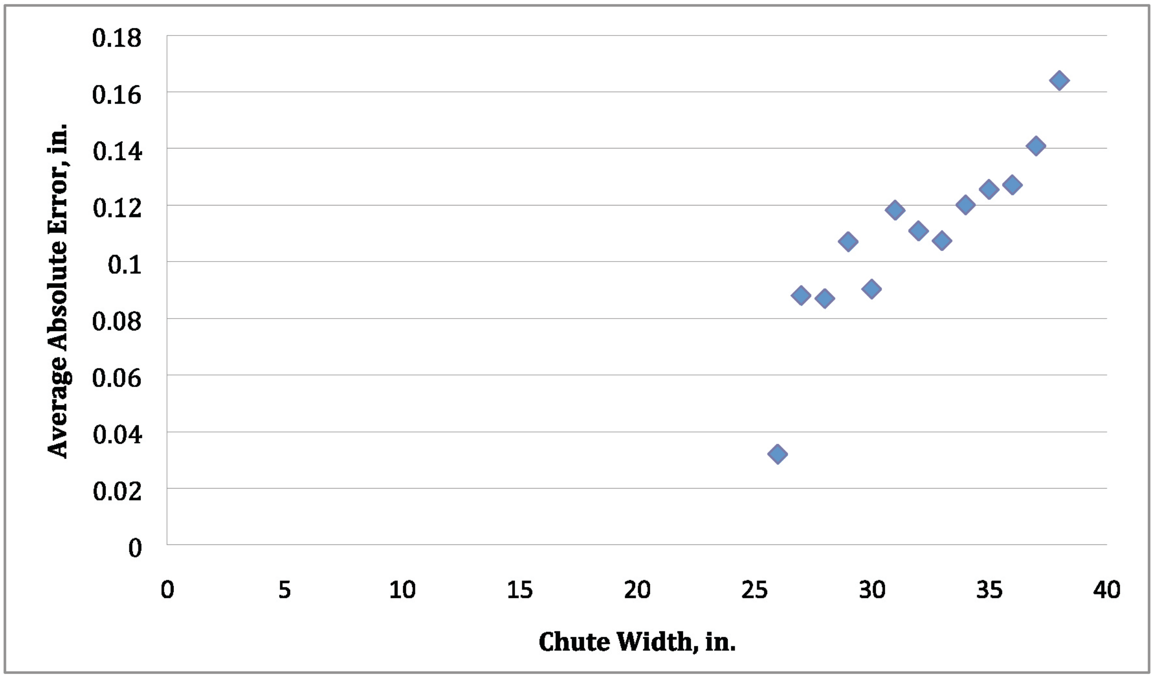

Figure 10. Chart showing absolute average error that can be applied to different chute widths as a result of the centering test using the 14 in. square. As the chute increases in width the absolute average error increases as well.

From the repetition test statistics, it was concluded that were no significant differences in repeatability when taking measurements from positions 1, 2, or 3, however there was a significant difference in the repeatability of readings taken on positions 4 and 5 as seen in Figure 11. The difference in average absolute error between position 4 and 5 measurements was 0.16 in. Positions 4 and 5 were the left and right shifts, so this supports the results that were obtained in the positioning test, noting the effect of measurement of target representing a non-perpendicular plane to the sensors. However, and to clarify, the repetition test was not meant to compare measurements at different positions, but rather to quantify the variability among measurements repeated on the same target area, for five different target areas.

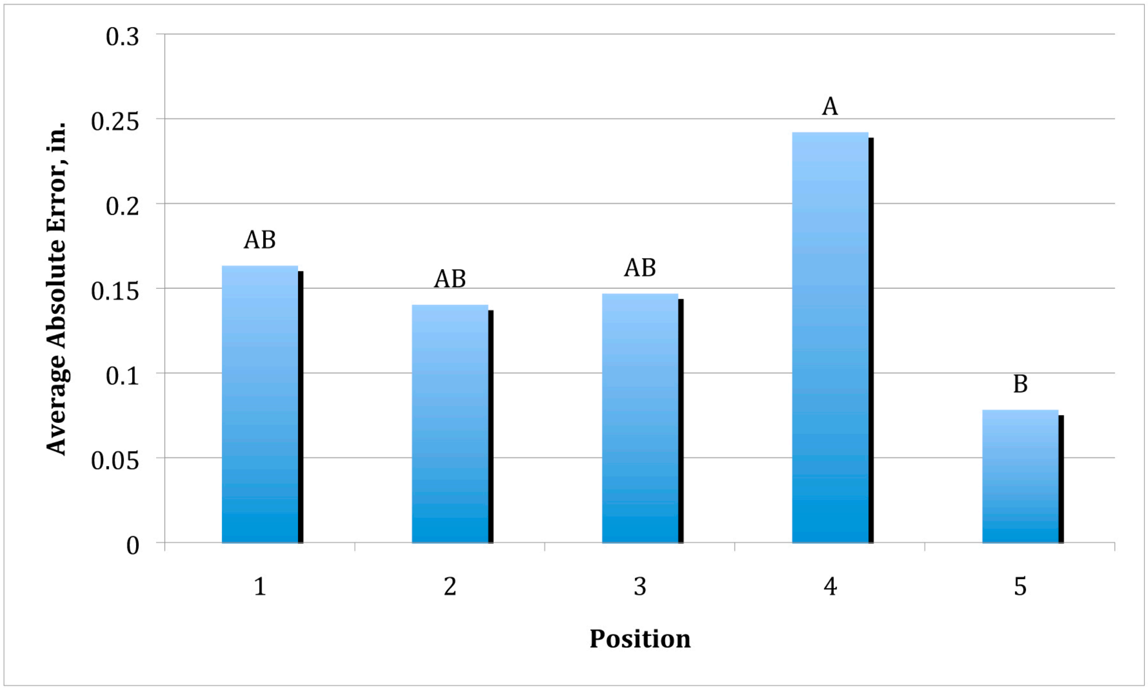

Figure 11. Bar graph illustrating the measurement repeatability of each position of the target in the repetition test. Means with different letters are significantly different (student's t-test, $p < 0.05$).

The dry color test revealed that there was a significant difference in sensor repeatability when the target was black versus all of the other common colors applied except for grey as seen in Figure 12. The difference in average absolute error between the color black and the color brown was 0.65 in. The wet color test was performed to gain some understanding of the potential effects that wet animal fur would have on the sensors as opposed to dry fur. The wet color test revealed that there was a significant difference in the color black and all of the other colors used in the test and it demonstrated an increased absorption of infrared light under wet conditions, resulting in greater measurement error as seen in Figure 13. The difference in average absolute error in the color black and brown was 6.76 in. Based on this test, the producer would need to avoid measurement of black animals especially in wet conditions without something to that would cover the black fur and would allow the infrared light to adequately reflect back to the sensor.

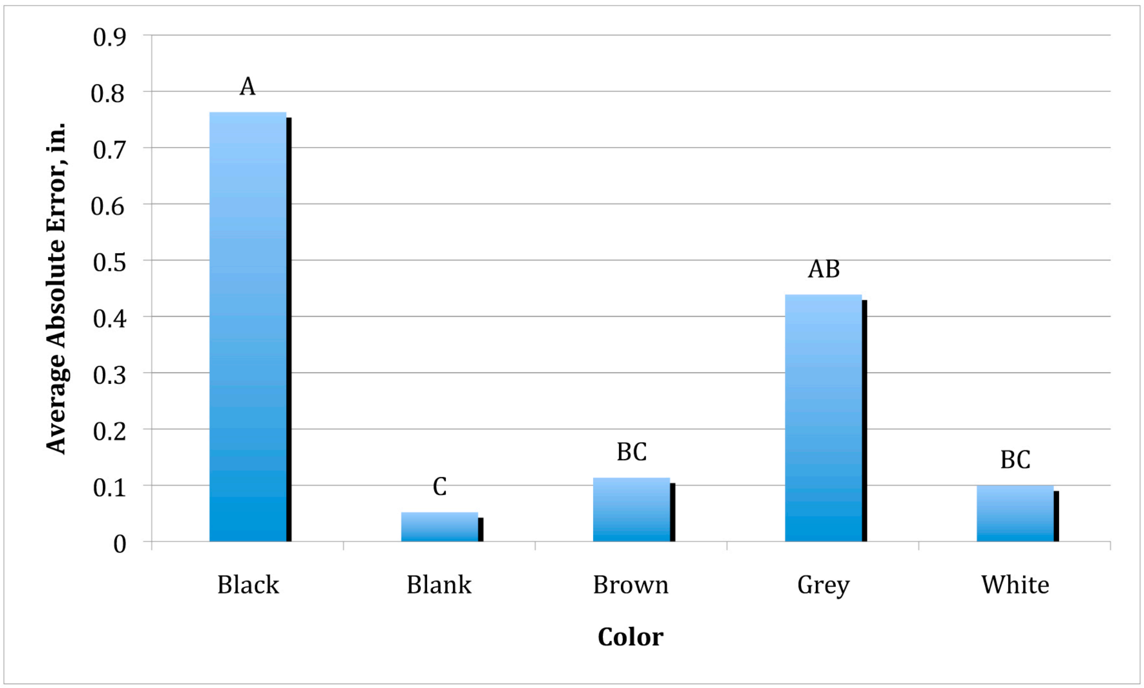

Figure 12. Bar graph illustrating the measurement repeatability of each color in the color test in which each piece of felt was left dry. Means with different letters are significantly different (student's t-test, $p < 0.05$).

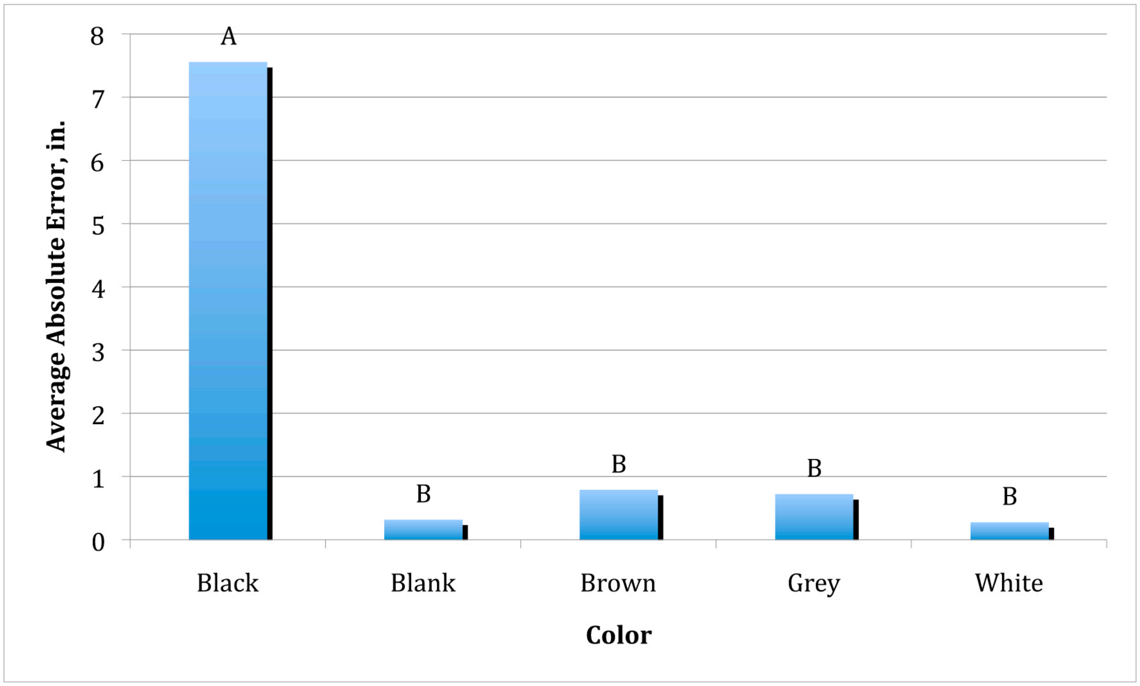

Figure 13. Bar graph illustrating the measurement repeatability of each color in the color test in which each piece of felt was soaked with water before being measured. Means with different letters are significantly different (student's t-test, $p < 0.05$).

The powder test revealed a significant difference between repeatability when measuring the black cloth at different target distances. The results shown in Figure 14 suggest that the infrared light absorbing effects of the color black can be counteracted by simply covering the surface with a more reflective color such as talcum powder. This could be a possible gateway for giving this sensor the ability to measure cattle of all hair coat colors. More testing needs to be done to determine if there are better, more efficient alternatives to applying talcum powder on each individual animal.

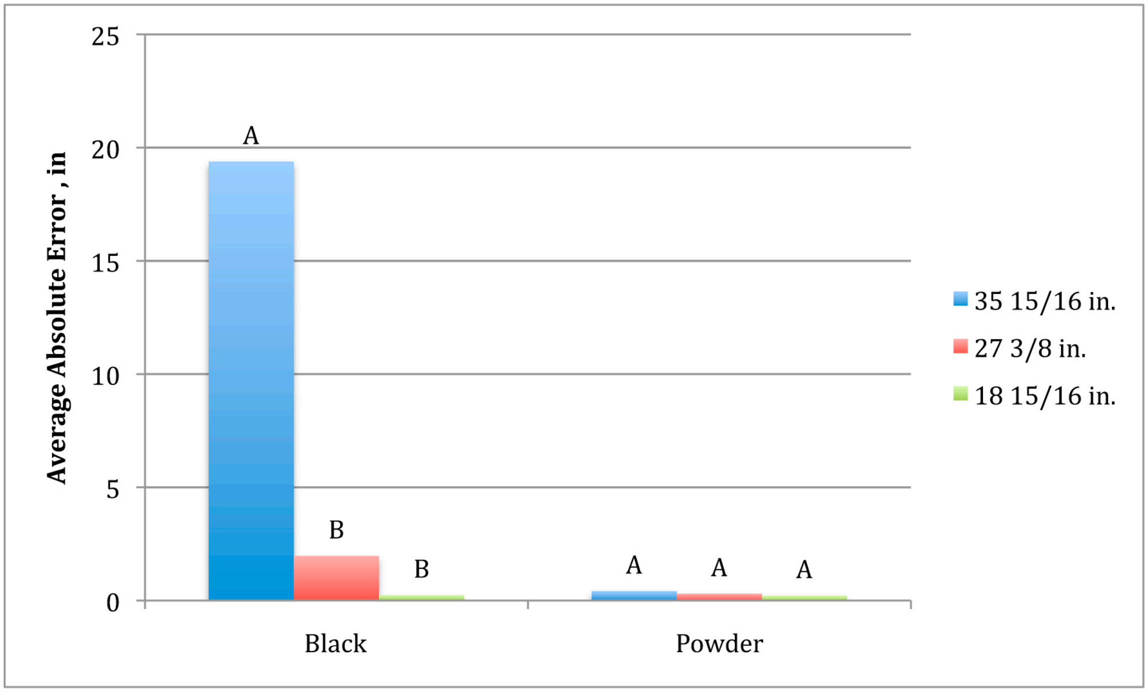

Figure 14. Chart comparing the repeatability of measurements at heights of 18-15/16 in., 27-3/8 in., and 35-15/16 in. for black cloth and black cloth coated with talcum powder. This is a comparison of error as a function of height, grouped by powder treatment. Means with different letters within each group are significantly different (student's t-test, $p < 0.05$).

The first tests conducted comparing visual measurements of one person to infrared sensor measurements revealed many flaws in how these animals were being measured. The error of the infrared sensor measurements was significantly higher than that of the visual measurements as seen in Figure 15. The difference in average absolute error of the two methods was 0.47 in. Contributing factors to this error could have been the wide freestanding position in the alley and the black coat color. This alley, which was 29.5" wide, was wider than the squeeze chute, which was 28" wide, that was in front of it hence it would allow a slightly wider range for cattle to shift left and right potentially affecting infrared sensor measurements.

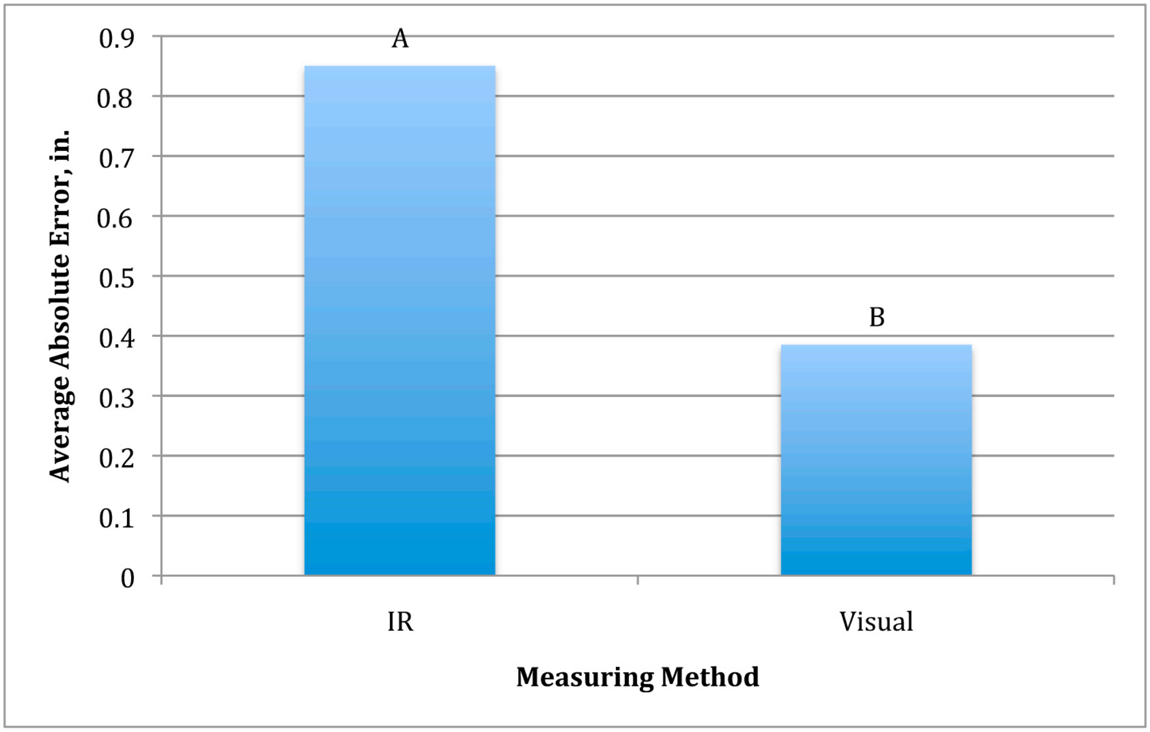

Figure 15. Repeatability of the infrared sensor and the visual measurement methods for the alley test. Means with different letters are significantly different (student's t- test, $p < 0.05$).

The comparison of visual readings vs. sensor readings by positions revealed no significant differences when grouped by position as seen in Figure 16. Positions in these analyses have been abbreviated as follows: freestanding = FS, free/squeezed = F/S, head caught = HC, head caught/squeezed = HC/S.

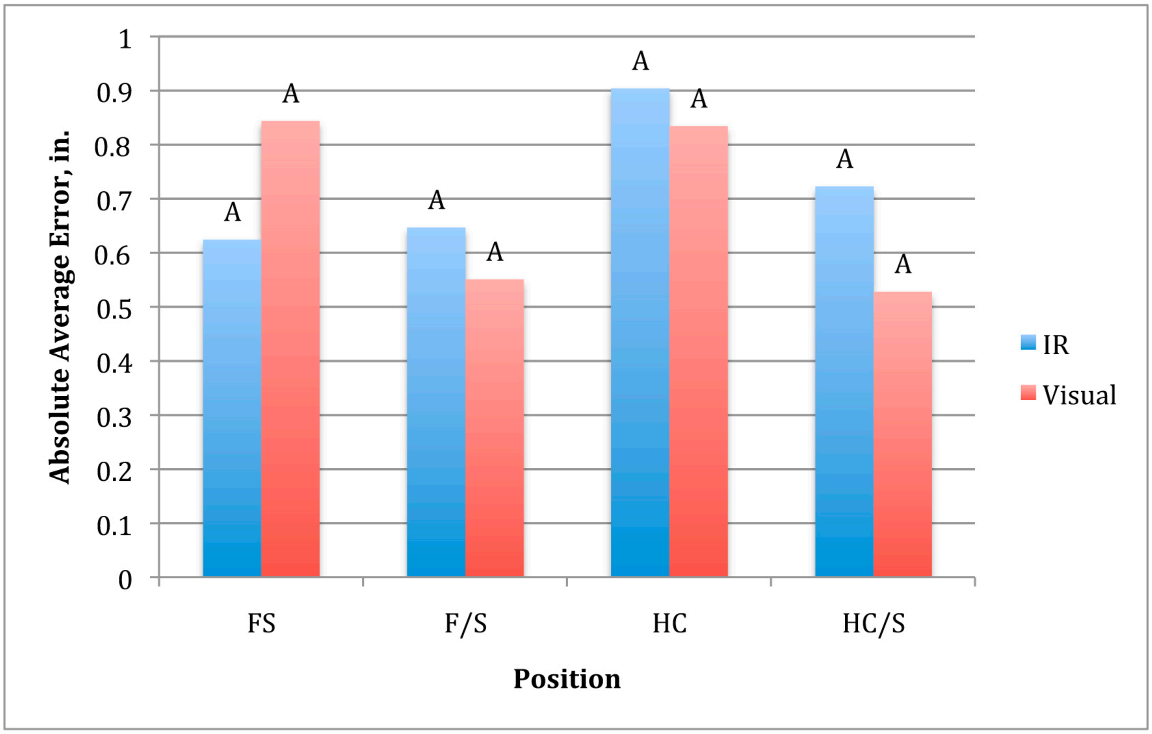

Figure 16. Comparison of repeatability of visual vs. sensor measurements, grouped by position for chute test. Means with different letters within each group are significantly different (student's t-test, $p < 0.05$).

The comparison of visual and IR sensor measurements across positions revealed a significantly higher error (or lower repeatability) for the head caught position when compared to the free standing and free/squeezed. The visual measurements revealed no significant differences across positions at the $p < 0.05$ level as seen in Figure 17. While not significant in this test, this analysis suggests that repeatability in hip height measurement may be improved with some type of restraint. Freestanding does not appear to be the best position in this test based on the error analysis. From tests such as these, recommendations can begin to be made on how to properly use these sensors to measure animals, as well as recommendations on standard methods for measuring visual hip heights.

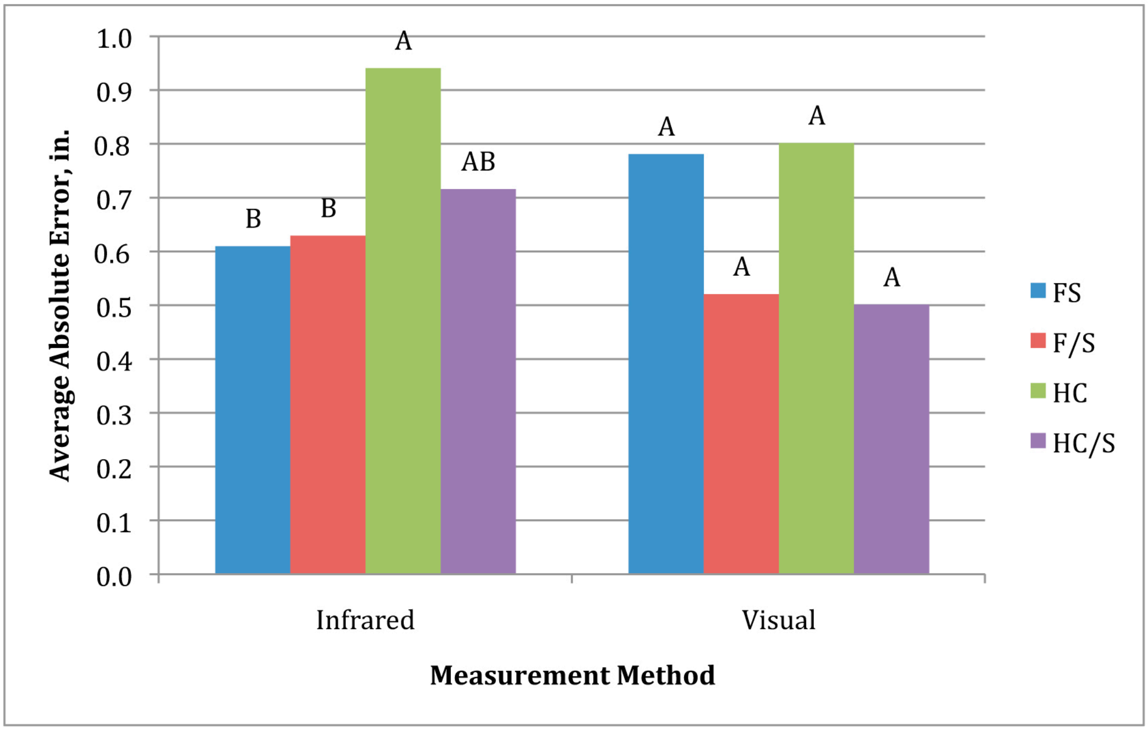

Figure 17. Comparison of measurement repeatability as a function of position, grouped by measurement method. Means with different letters within each group are significantly different (student's t-test, $p < 0.05$).

For the comparison of visual hip heights by position, all of the visual hip heights were averaged for a given animal and then compared to each individual measurement, to calculate a measurement error. These measurement errors were averaged for each position as seen in Figure 18. The only significant difference that was found was between the free/squeezed position and the head caught position. The difference between these two positions was 0.47 in. This test demonstrated that as the methods of restraint are changed, hip height measurements can either increase or decrease on average according to the method being used. For example, hip heights measured in the head caught position were significantly less than those in the freestanding position for the same animal.

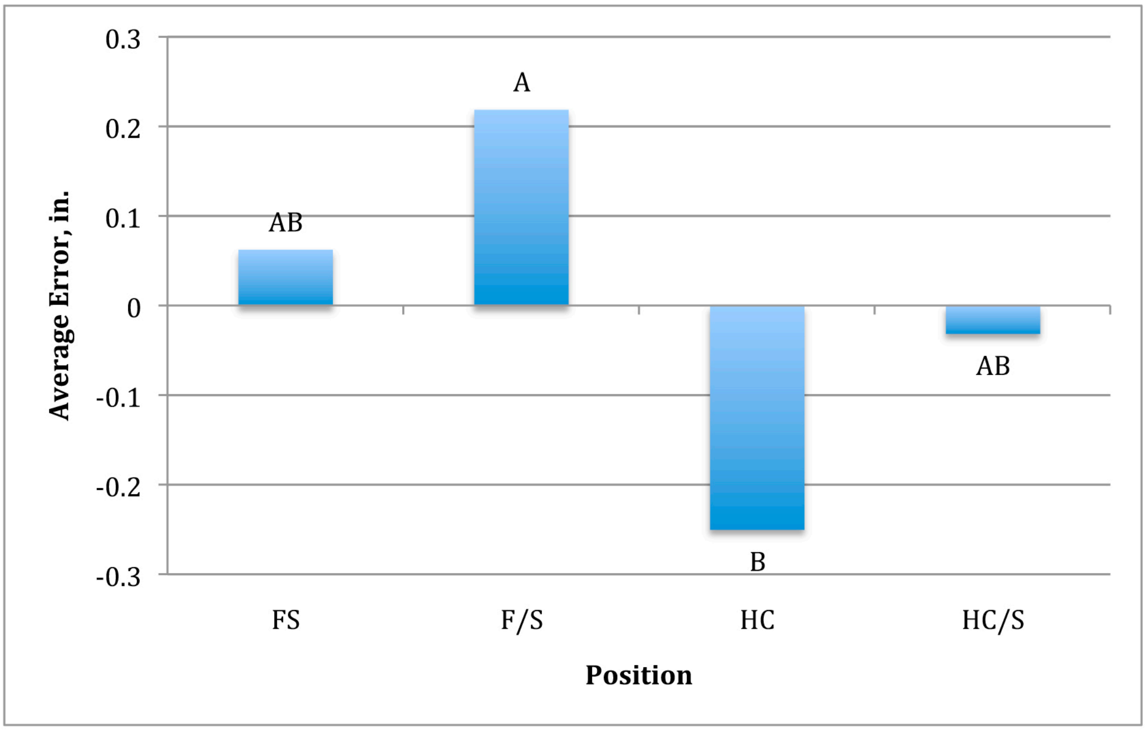

Figure 18. Chart showing the differences in average error among the different positions tested for visually measured hip heights. Means with different letters are significantly different (student's t-test, $p < 0.05$).

For the comparison of talcum powder effects across positions, the only significant difference reported in the statistics was for the free/ squeezed position. There was a significant difference in the effects of talcum powder on the sensor readings as well as without talcum powder for the head caught/squeeze position as seen in Figure 19. The difference in using talcum powder and not using talcum powder for IR sensors is 4.43 %. Again, this is a percentage difference in hip height, not difference in inches.

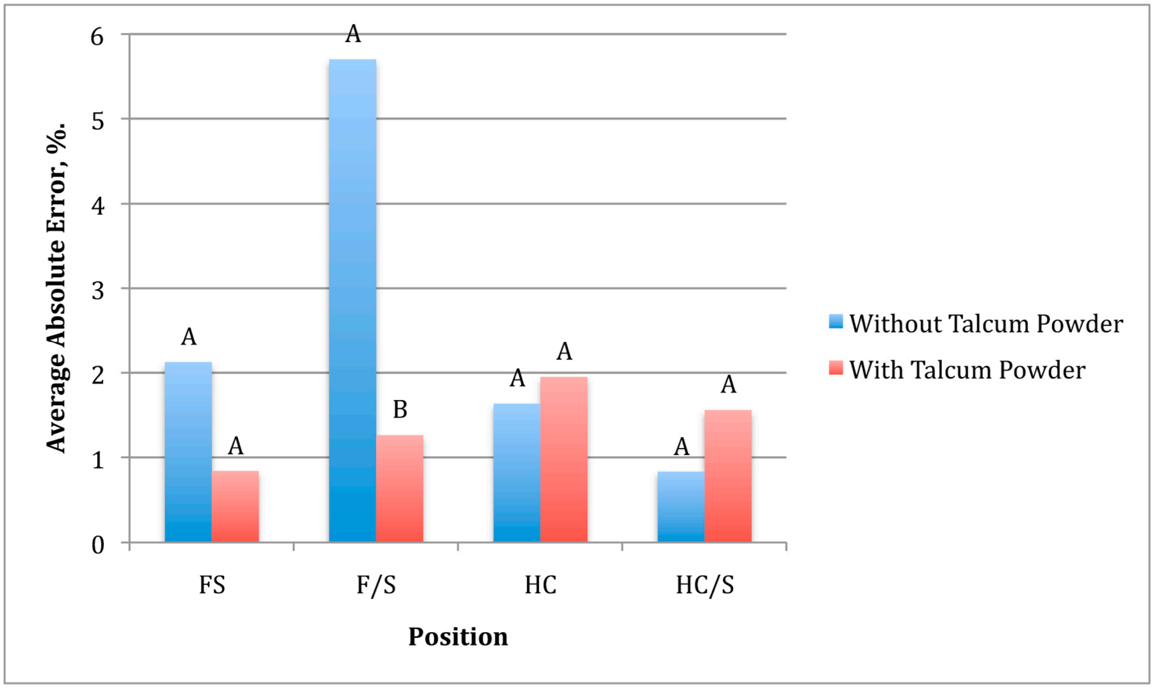

Figure 19. Chart showing the effects of using talcum powder and not using talcum powder, grouped by position. Means with different letters within each group are significantly different (student's t-test, $p < 0.05$).

As seen in Figure 20, for the comparison of cow position for IR sensor readings without talcum powder, the only significant difference found was in the free/squeezed position, which produced significantly less repeatable measurements than the other three positions. A difference of 3.58%, or 1.75 in. based on a 50 in. hip height, error separated the free/squeezed method from the third most repeatable position, free standing. For the comparison of cow position for IR sensor readings with talcum powder, the head caught position was significantly less repeatable than the free/squeezed and freestanding but not significantly different from the head caught/squeezed positon. The difference in average absolute error between the head caught method and free/squeezed method with talcum powder was 0.68%.

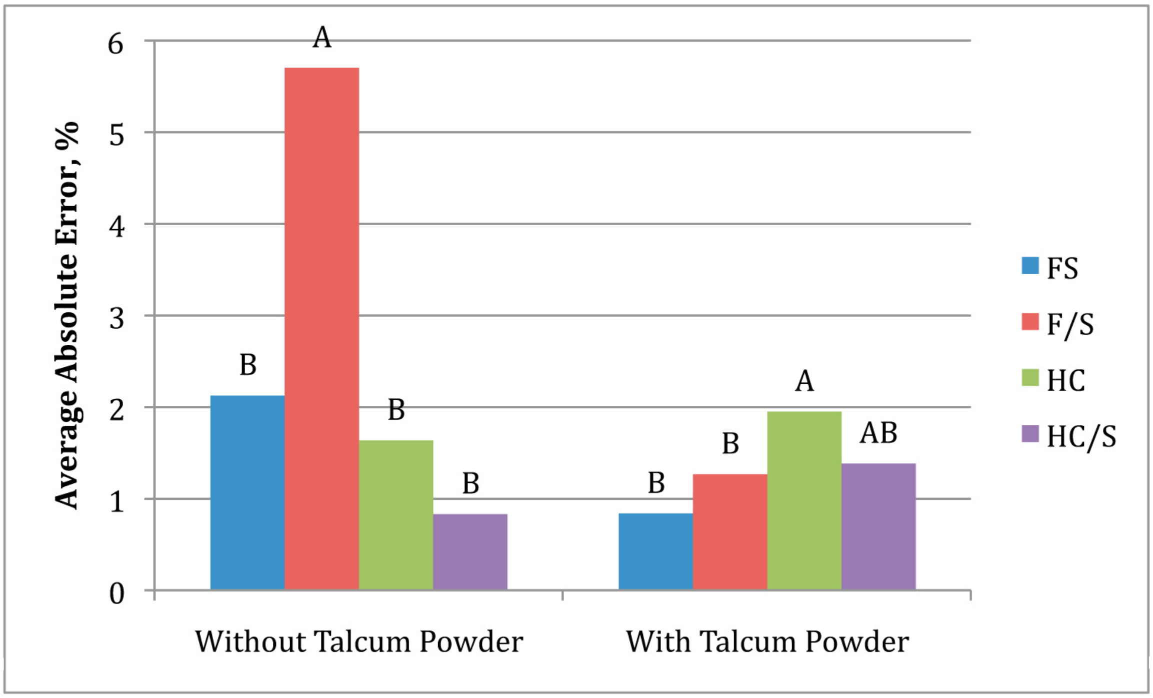

Figure 20. Chart showing measurement repeatability of four different positions without talcum powder on IR sensor readings. Means with different letters within each group are significantly different (student's t-test, $p < 0.05$).

HIP HEIGHT/FRAME SCORE ANALYSIS

This analysis utilizes the data from the visual vs. sensor comparison test to show the correlation between the visual and infrared sensor measurements. The points in Figure 21 represent the overall average measurements of all four positions/constraints for each animal in the test. This overall average was used in order to achieve a value as close as possible to the animal's actual hip height measurement for each measurement method. The coefficient of determination (R^2 value) for visual hip height versus infrared sensor hip height was 0.7542, with visual hip heights being equal to about 97% of the indicated infrared sensor hip heights, as indicated by the slope of the fitted linear model. This model demonstrates that the IR sensors have the potential to provide data similar to that obtained when visually measuring cattle hip heights.

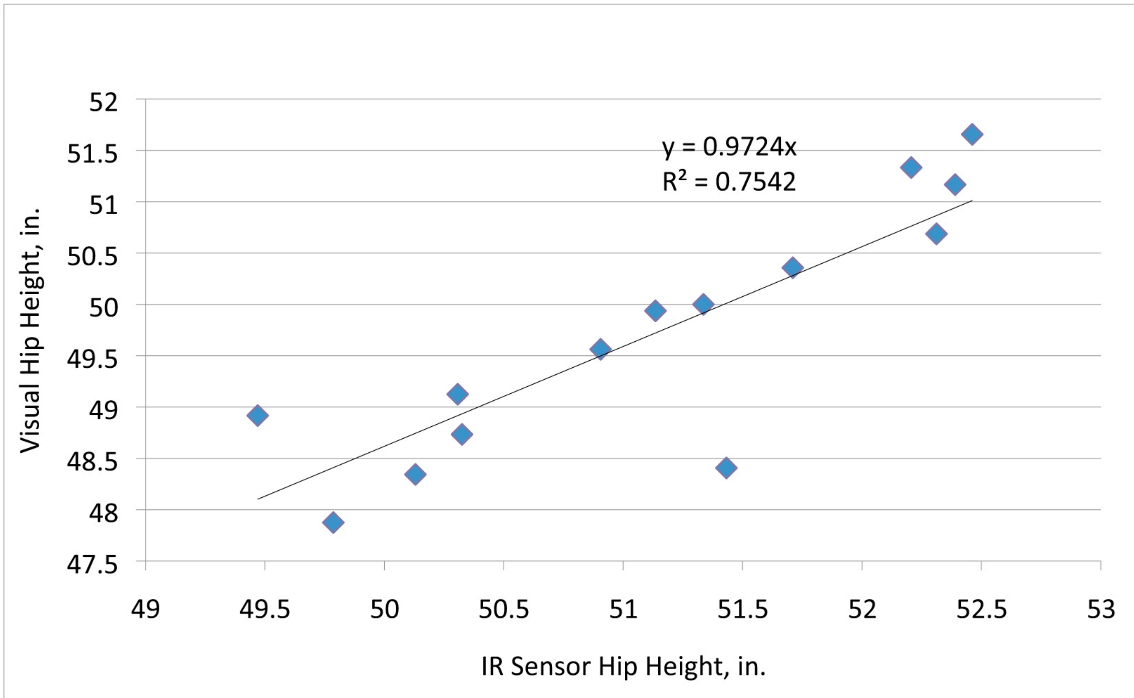

Figure 21. Scatter plot showing the correlation of the average hip heights per animal of the visual measurements and the average hip heights per animal of the infrared sensor measurements. The trend line provides an R^2 of .7572.

After analyzing the trend amongst the hip height averages in the previous figure, the average hip height data for each measurement method and the animal ages were used to calculate a frame score for each measurement method and each animal. The correlation, as seen in Figure 22 provided a coefficient of determination of 0.7204 and a slope of 0.97, suggesting that frame scores calculated from visual hip heights would generally expected to be 97% of those calculated from infrared sensor hip heights. The points reported are rounded to the nearest tenth as opposed to actual frame scores, which are reported as whole numbers. The reason for doing this was to show how close the numbers from the actual calculation were instead of allowing the rounding of numbers to affect the correlation.

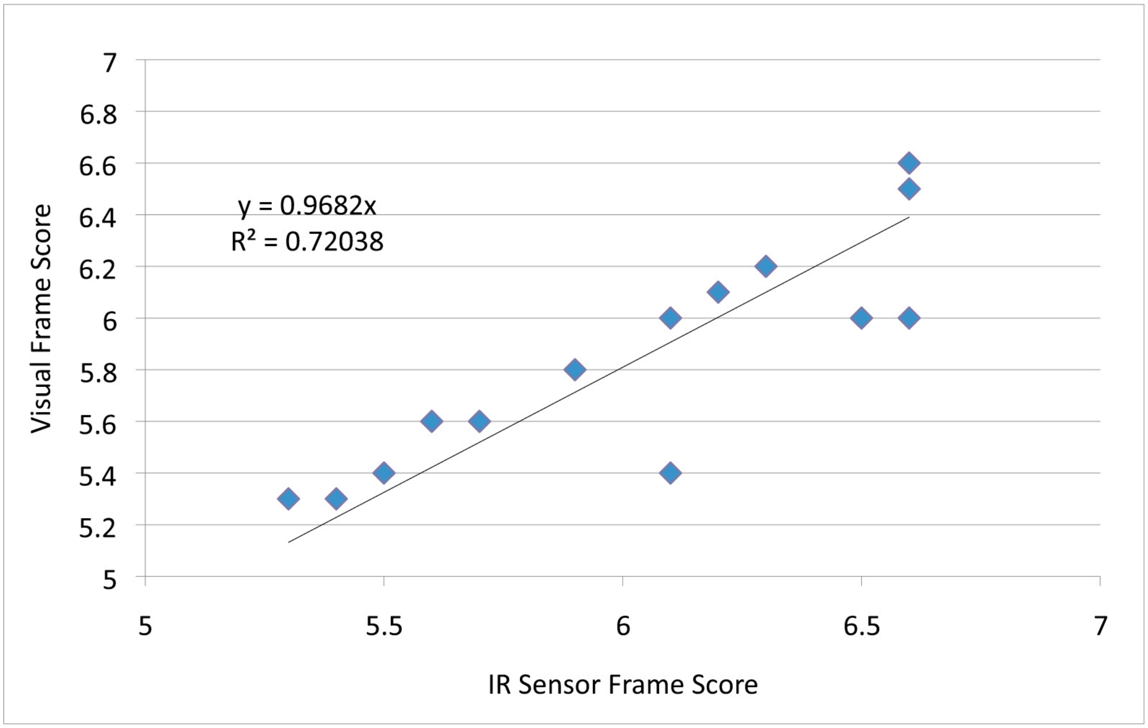

Figure 22. Chart showing the correlation of frame score between the visual and the IR measurements. The trend line provides an R^2 of 0.7204.

CONCLUSION

From the data collected in the centering test, it was apparent that the measurement error increased as the chute width increased. An increase in chute width allows the animal more lateral movement. This means that if live cattle should shift in the chute while being measured, the measurements could change with the animal's position. However, this may not be of major concern because the magnitude of differences demonstrated in measured hip heights as a function of this shift were demonstrated in this study to generally be less than 0.2 in., which is less than the resolution to which most visual hip heights are made. One major reason for the inconsistencies in the data could be a result of the target surface not being perpendicular to the sensing angle. This could be an explanation for why there were inconsistencies in the sensor readings for the stationary targets. The repetition test data supports this idea because there is a significant difference between the right and left positions under the sensors. This is not to be confused with the centering test. As discussed, the repetition test was not meant to compare measurements at different positions, but rather to quantify the variability among measurements repeated on the same target areas.

The conclusions we can draw from the data of both of the color tests are that the sensors do not respond well to the color black. This could cause a major issue in taking this technology further without taking this into consideration because a majority of cattle, especially in the Southeast, are predominantly black in color. This is most likely due to the fact that the color black does not reflect infrared light well; the measurements indicated by the software were erratic on many black targets in this study. From the wet color test, it can be seen that wetness exaggerates these effects. The issue with the color black was reduced drastically through the use of talcum powder being applied to the target, however the practicality of this solution is yet to be evaluated on a large or commercial scale. If these types of remote sensing systems are going to be considered in the future for animal application, further testing needs to be done to ensure that the color black will not have an effect on gathering accurate and precise measurements, that a more efficient solution can be found to counteract black colors other than applying talcum powder to each individual animal, and that the sensors can withstand the harsh environments of cattle production.

During the live cattle tests, the animals usually maintained proper "natural" posture when unconstrained also known as the freestanding position. When a squeeze or head catch was applied, the animal adjusted posture to try resisting the restraint, which could cause the data to become skewed. The sensors were very unstable when reading some of the black animals. White talcum powder seemed to counteract the effect of black on the sensors when applied to black cattle. There was no observational explanation for why Free/Squeezed was so different from the rest of the positions in the test conducted without talcum powder other than the cattle tended to adjust their positions more frequently than the other positions. For the comparison of talcum powder across positions, the statistics indicate there is only one significant difference, but there were more observed differences in the field and on the charts. The squeeze could have had an effect on posture or throwing the animal out of sensor view in the compare visual vs. sensor across positions. The difference could be caused by the tendency of cattle to have irregular posture when caught by the head gate to try and free themselves. There were issues associated with each position. When you catch the head, regardless if the animal is squeezed, the animal tends to arch its top because it is trying to pull its head out of the head gate. This leads to false measurements when we take a sensor reading. The freestanding position leads to an excessive amount of lateral movement, which also leads to false measurements because the sensors are potentially influenced by the drop-off of the hip, along the animal's side.

The hip height and frame score analysis showed a relatively strong correlation between visual and infrared sensor measurements; the correlation between hip heights demonstrated an R^2 of 0.7542 and the correlation between frame scores produced an R^2 of 0.7204. These results show that this infrared sensor system has the potential to measure hip heights as well as someone measuring hip heights visually. More testing and analysis should be done to confirm the results seen here.

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